Cosmic Ray Rates and DAQ Implications

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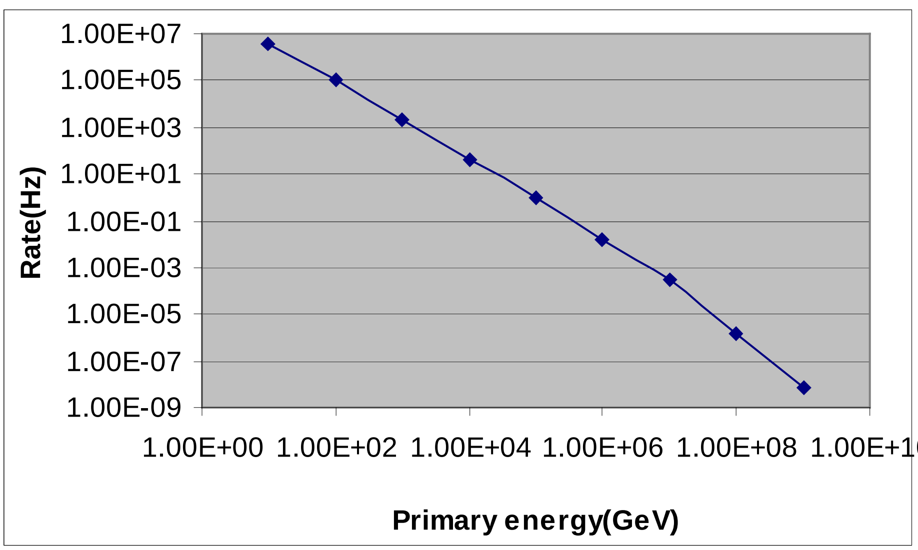
These notes are primarily intended to gauge the effect of cosmic rays on the detector and DAQ system due to the continuous flux of cosmic rays. Since the baseline detector will have a live time of nearly 100%, in order to allow for asynchronous event selection we need to understand what this will do to the DAQ system. For beam events all the rates will be down by a factor of 10^5, and on average there will be a random muon, mainly from low energy primaries, in every fourth time slice. (Or every other time slice if there is a smaller overburden.)

Cosmic Ray Flux

Fluxes of particles hitting a NOνA sized detector. At 10GeV the flux is:

$$0.1(m^2 \cdot s \cdot sr \cdot MeV)^{-1} * 134m * 15m * 2sr * 10^4 MeV = 4 * 10^6 \, particles/s$$

From here differential flux falls at $E^{-2.7}$, and integral flux as $E^{-1.7}$, or a factor of 50/decade in energy. Beyond ~3PeV it steepens to a power law of 3.3, and integrally 2.3 or 200/decade in energy. This leads to an interaction rate as shown:



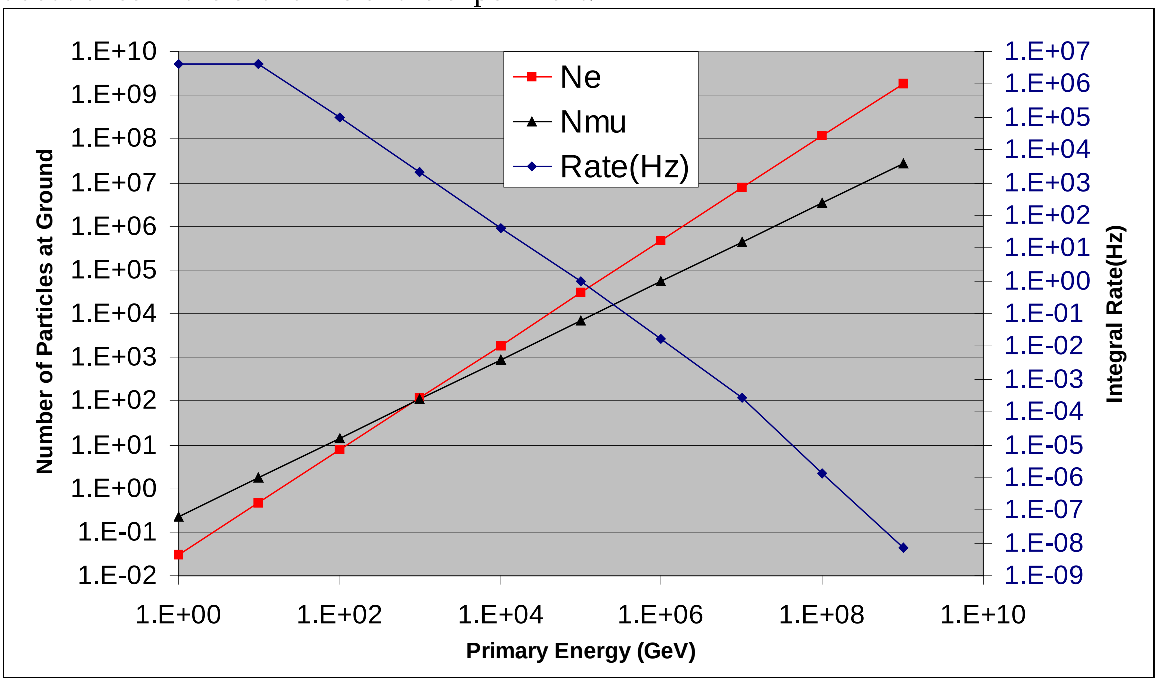
The actual acceptance of events at these energies is complicated. Since the area of an event grows with energy, so will the probability of detection. It is not a simple scaling, and usually simulated with the standard cosmic ray simulation code CORSIKA. At higher energies the rate should be somewhat higher, since the angular acceptance is greater, and effective area is larger than the detector area.

Particle fluxes in Extensive Air Showers (EAS)

In the following graph I have simply assumed the acceptance is the area of the detector times 2 for the angular acceptance. This hides the detail of the detector acceptance, but allows some qualitative, and order of magnitude estimates of rates of expected events.

At low energies the ground level flux is dominated by muons, shown by black triangles. Since the maximum of the shower development is very high in the atmosphere the only particles that survive to ground level are the weakly interacting muons. As the energy increases the shower maximum moves closer to ground level, and the much more numerous electrons, shown as red squares, survive to ground level. The approximate rate for a detector 15m*134m is shown by the rate curve, with blue diamonds, and the legend on the right side of the plot.

The number of particles at ground level can become very large, 30 million muons, and over a billion electrons. These events are rare, and would hit the detector directly only about once in the entire life of the experiment.



Detected Muons

The number of muons seen in the detector for each event depends on the lateral distribution of the particles in the shower. While it is true that there can be tens of millions of muons in a shower, the detected size of the shower and the limited size of the detector limits the number that will actually be detected.

The radial density of muons in an air shower can be approximated by the NKG distribution, approximated as:

$$\rho_\mu(r) = 18r^{-0.75}\left(1+\frac{r}{320}\right)^{-2.5}\left(\frac{N_e}{10^6}\right)^{0.75} muons/m^2$$

N_e is the number of electrons observed, which is related to the primary energy by the equation:

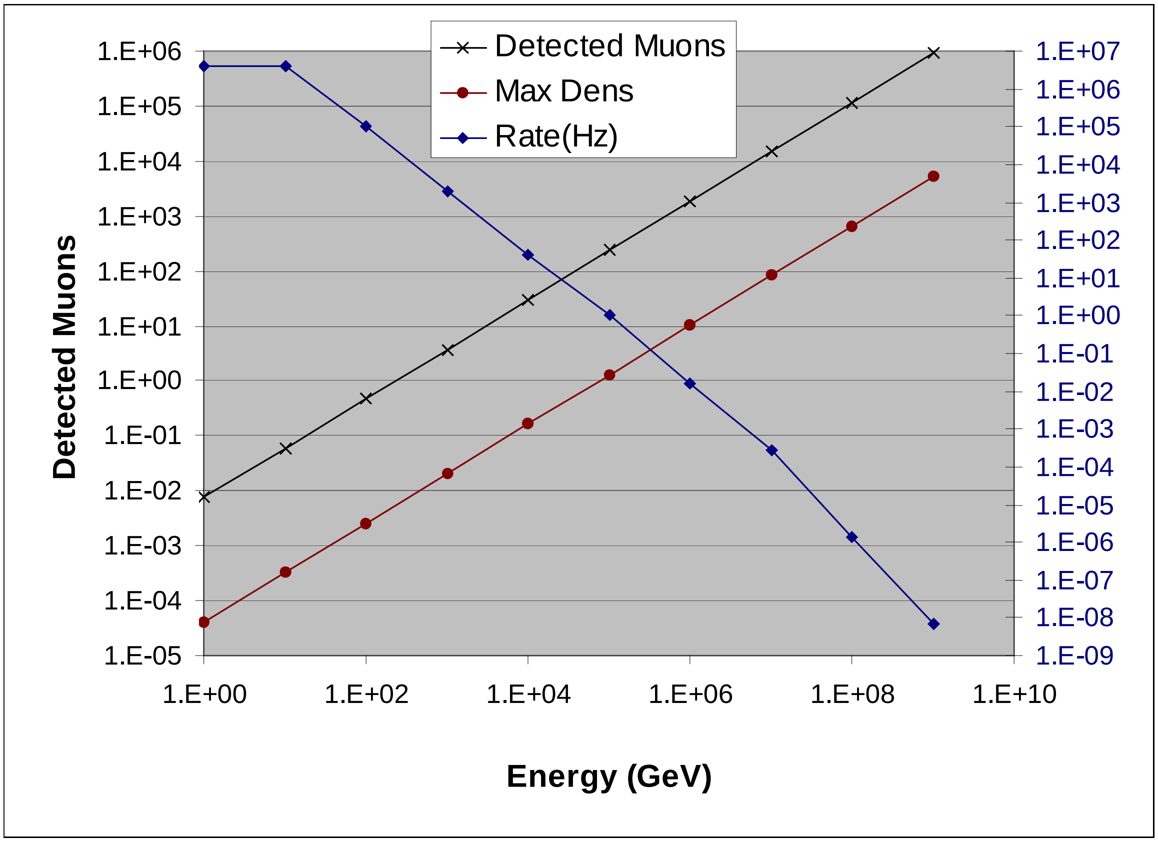
$N_e \propto \left(\frac{E_0}{E_c}\right)^{1+\varepsilon}$, normalized at a given point N_e=3x10^4 @E_0=10^{14}eV, and ε~0.2.

These approximations were used to produce the number electrons and muons in the figure. The assumption is that the electromagnetic component of the showers would be absorbed in the overburden, and only the muon component would be detected. The radial distribution can be used to determine maximum number of muons that would be detected. I have calculated this number simply assuming a vertical shower, the given radial distribution and a shower centered on the detector. In general for cosmic ray showers, a shower at steeper angle would have a similar particle density, but occur at lower rates due to the greater atmospheric attenuation. I have also calculated the maximum density, which is about 100 times smaller than the total number of muons in a shower.

The number of detected muons from primaries of energy less than ~1TeV is of order one. Indeed, this is the most likely number of muons to be seen in an event, and typically comes from these low primary energy showers. The rate at higher energies, around 1PeV can deposit on the order of 1000 muons in a single event, and should occur at a rate of about 1 every minute or two.

The effect of this on the DAQ system are expected to be miniscule, since the background rate of the single muons should be on the order of 250kHz. As the energy increases, the number of detected muons increases nearly proportionally, but since the flux is falling at an even greater rate, there should not be a problem from the DAQ perspective. The effect will actually be less severe, since the high density and multiplicity will limit the amount of data since there will be multiple hits on a single cell.

Typically you would get about 1200 hit cells for each muon. Since the showers particles all arrive instantaneously, from the standpoint of the digitization, instead of getting 1200 *10^6 hits, the limit occurs in a fully illuminated detector, or ~750kHits. In a typical 10ms time slice there are 250kHz*1200*.01s, or 4 million hits. Therefore a fully illuminated detector would see only a 20% increase in the data rate to trigger processors. Even at higher energies, the once per experiment variety, the number of muons goes as high at 1 million.



Summary

While it appears that there will be large events occurring in the detector due to extensive air showers, the absolute rate of these is relatively small. It does not appear that this should have a large impact on the DAQ system due to the fact that the system is already dealing with a large rate of single muon events coming from the much lower energy, but much higher flux primaries.